DEDICATED MEASUREMENT CAMPAIGN FOR DEFINITION OF ACCURATE REFERENCE PATTERN OF THE VAST12 ANTENNA

Sergey Pivnenko, Olav Breinbjerg
Department of Electrical Engineering, Technical University of Denmark
DK-2800 Kgs. Lyngby, Denmark, sp@elektro.dtu.dk

Sara Burgos, Manuel Sierra-Castañer
Universidad Politécnica de Madrid. E.T.S.I. de Telecomunicación
Ciudad Universitaria, 28040 Madrid, Spain

Håkan Eriksson
SAAB Microwave Systems
SE-412 89 Gothenburg, Sweden

ABSTRACT

In this paper, three possible approaches for definition of a highly accurate reference pattern of a reference antenna are described and their pros and contras are discussed. Following the most reliable approach, a dedicated measurement campaign was planned and carried out in 2007-2008 for definition of the highly accurate reference pattern of the VAST12 antenna. In planning the campaign, conclusions from the first comparison campaign with the VAST12 carried out within the ACE network in 2004-2005 were taken into account and these are also presented and discussed. Some typical measurement errors and uncertainties are listed and briefly discussed.

Keywords: accuracy, inter-range comparison, metrology, standards, reference.

1. Introduction

The 12 GHz Validation Standard (VAST12) Antenna was designed and manufactured at the Technical University of Denmark in 1992 under the contract from the European Space Research and Technology Center [1]. The VAST12 antenna is shown in Fig. 1. The main purpose of the VAST12 antenna is to facilitate antenna test range intercomparisons for the European Space Agency (ESA).

In 2004 ESA has permitted the use of the VAST12 antenna for the European Union network "Antenna Center of Excellence" – ACE [2]. Within the Activity 1.2 of the ACE network, the First Facility Comparison Campaign was carried out with the VAST12 antenna during 2004-2005, which involved several universities and private companies with total of 9 different measurement facilities. The results of the campaign are documented in the report [3] available from the Antennas Virtual Centre of Excellence portal [4].

A highly accurate reference pattern of a reference antenna, such as the VAST12 antenna, is clearly necessary, since its existence allows benchmarking of the antenna test ranges and estimating their measurement uncertainties. Potentially, it also gives a possibility to identify and correct errors in the applied measurement procedures by carefully analyzing the results of pattern comparisons supported by knowledge of pattern deviations from typical errors of the measurement setups.

Figure 1. The 12 GHz Validation Standard Antenna.

In this paper, three possible approaches for definition of a highly accurate reference pattern are described and their pros and contras are discussed. Following the most reliable approach, a dedicated measurement campaign was planned and carried out in 2007-2008 for definition of the highly accurate reference pattern of the VAST12 antenna.

In planning the campaign, conclusions from the first comparison campaign with the VAST12 carried out within the ACE network in 2004-2005 were taken into account and these are also presented and discussed. Some typical measurement errors and uncertainties are listed, while their extensive investigation and effective compensation, including the residual uncertainty estimate, are presented in a companion paper "Characterization of measurement systems through extensive measurement campaigns".

2. The 12 GHz Validation Standard Antenna

The VAST12 antenna represents an offset shaped parabolic reflector with circular aperture, see Fig 1. The feed is a corrugated horn with a polarizer allowing changing from linear to circular polarization. In order to make the antenna rigid and thermally stable, the support structure is made of carbon-fiber reinforced plastic (CFRP) sandwich, while the mounting flange and dish suspension points are made of stainless steel. The reflector is made of high density acrylic foam covered in front and in back with several layers of fibers in four directions. The reflecting surface is silver painted with a protective paint on top. The dimensions of the VAST12 are 842mm x 508mm x 939mm and the weight is about 20 kg. The operating frequency is 12 GHz. A complete description of the design, manufacturing and testing of the VAST12 antenna is given in [1].

For the purpose of facility comparisons, three coordinate systems (CS) are defined: the optical CS is defined by a mirror cube attached at the top of the reflector, the mechanical CS is defined by the mounting flange and using a level placed on the support arm, and the electrical CS is defined by the peak of the far-field co-polar pattern and the minimum of the cross-polar pattern [1]

3. Establishment of the Reference Pattern

The difficulty of establishing a reliable reference pattern is associated with insufficient trust to the results obtained at some particular facility. In the case that some non-identified or unknown errors are present in the measurement procedure, the obtained uncertainty estimate is wrong as well as the results of the benchmarking.

Several approaches can be considered for the definition of the reference pattern.

Approach N1: Measurements at several facilities

One obvious way of improving the reference pattern is to measure the antenna at several facilities, preferably by different techniques, and average the results. The purpose of this approach is, obviously, reducing the risk of non-identified errors and thus increasing the trust to the results. However, effective decreasing of the resulted uncertainty is only possible, if the uncertainties of the involved facilities are similar, which should be demonstrated by carrying out the uncertainty estimates at each facility with a standardized approach. The last does not exist yet, though several attempts have been made for its development, for example, the well known 18 terms NIST error budget for planar near-field measurements [5]. If the estimated uncertainties are different, proper weighting can be applied, such that the resulted uncertainty is decreased.

There are some disadvantages of this approach. For example, uncertainties of reproducing the coordinate system (both orientation and origin location) add to the list, standardized uncertainty estimates are not developed yet for many measurement techniques, antenna traveling takes time, facilities willing to participate should be found and agreements with them should be made.

Approach N2: Several measurements at single facility

Another way of improving the reference pattern and thus increasing the trust is the following. An antenna pattern measured at only one facility can be completely trusted, if it is proven that *all* errors are identified and properly corrected, uncertainties are minimized, and their residual effects are properly estimated.

Obviously, the main difficulty lies in ensuring that *all* errors are identified, which represents a serious challenge. To this end, facility comparisons play a key role in solving this problem as these provide effective means to identify any possibly yet unknown errors of some particular technique. The comparison campaign carried out within ACE in 2004-2005 [3] allowed identifying and helped to correct several mistakes and errors in the measurement procedures of the participating facilities. Some conclusions of the above campaign, relevant for this discussion, are given in the next section.

Special techniques can be applied for minimizing various uncertainties and their effect on the radiation pattern. Averaging of two patterns in which the effect of some uncertainty is represented differently, most desirably in an opposite way, is proven to be an effective technique of suppression or reduction of the effect of that uncertainty. Well known examples are the following: multiple reflections and averaging the results measured at 2 distances differed by a quarter of wavelength, wall reflections or compact range reflector edge diffraction and averaging the results measured at two or more AUT locations in the chamber, averaging two nominally identical measurements to improve signal-to-noise ratio and reduce the drift effects, etc. Making several measurements in the way described above and averaging the results, the uncertainty of the determined pattern is decreased.

Approach N3: several measurements at several facilities

A third way of improving the reference pattern is using a combination of the above two approaches. Several measurements are performed at each facility and the results are averaged, at each facility, aiming on reduction of the effect of uncertainties known to be the largest for that particular facility. The obtained best patterns from several facilities are then averaged in between thus forming the most reliable reference pattern with the remaining residual uncertainties reduced even more. The key requirement in this approach is the existence of a clear and easy repeatable definition of the antenna CS.

This last approach is being used in definition of the reference pattern of the VAST12 antenna within the ACE network.

4. Conclusions from the Facility Comparison Campaign with the VAST12 in 2004-2005

As it was already mentioned above, the complete results of the campaign are documented in the report [3]. Only few conclusions important for the present discussion are given below.

One lesson learned from the campaign was that even small errors can result in noticeable deviations of the obtained far-field pattern of such complicated antennas as the VAST12. For example, despite of a very careful mechanical alignment, slight bending of the horizontal axis under the weight of the AUT in a spherical near-field setup may result in deviations up to ±0.2 dB in the main beam of the co-polar pattern. Another example is that even using the calibrated probe, but forgetting to check its precise polarization alignment, can result in deviation of the polarization tilt angle in the peak of the AUT field up to 1° and thus deviations of the cross-polar pattern up to few decibels. One more example is that transformation from the measurement CS to the optical CS or to the electrical CS, which involves additional optical measurements and determination of the Euler angles, adds few uncertainties to the final result, which increases the deviations between patterns from different facilities even more. This last example clearly shows that the proper choice of the CS ensuring minimum amount of uncertainties is essential for the definition of accurate reference pattern.

Another lesson learned was that mistakes can always happen, especially in the complicated measurement procedures, and thus some self-checks are the very necessary means to ensure the quality of the results. This conclusion seems to be obvious, but in view of the high importance of the accurate reference pattern these self-checks must always be performed for the key alignments in the system.

Finally, it should be said that it was not possible to define an accurate reference pattern from the results of this campaign due to several reasons:

- Few mistakes made by the participants resulted in not quite accurate obtained patterns from some facilities.
- Only few facilities could provide uncertainty estimates and these were compiled according to rather different approaches, which did not allow their direct comparison.
- Results were provided in different CS, which did not allow collecting large enough amount of data in some particular CS.

5. Dedicated Measurement Campaign

Taking into account the conclusions mentioned above, a dedicated measurement campaign for definition of accurate reference pattern of the VAST12 antenna was planned. It was decided that only few facilities should participate and each involved facility should carry out a series of measurements with small modifications in the setup aiming on reduction of the effect of the largest uncertainties. In addition, thorough checks and additional adjustments, if proven necessary, should be performed in order to ensure absence of mistakes and highest quality of the results.

The chosen CS for the reference pattern was the mechanical CS, which can be directly implemented in many facilities and does not require any additional transformations.

It was agreed that the uncertainty estimates for the obtained patterns should be carried our according to a unified approach developed in the work package 1.2-2 “Standardization of Antenna Measurement Techniques” of the ACE network 2006-2007[6].

Three facilities participated in this dedicated campaign: the measurements at the Technical University of Denmark (DTU) were carried out in June 2007, at SAAB Microwave Systems (SAAB MS) in September 2007, and at the Polytechnical University of Madrid (UPM) in January 2008.

The measurements at DTU (spherical near-field facility) consisted of in total 14 full-sphere near-field acquisitions, which were aimed at estimate of influence and at reduction of the following uncertainties:

- Axes intersection and pointing of the mechanical setup
- Amplitude and phase drift and noise
- Receiver non-linearity
- Probe polarization and channel balance

- Multiple reflections between the AUT and probe
- Mounting structure interference

The final result is formed as a complex far-field average of 12 of the available full-sphere data.

The measurements at SAAB MS (compact range facility) consisted of in total 12 directly measured far-field patterns as cuts in the main and diagonal planes, which were aimed at estimate of influence and at reduction of the following uncertainties:

- Wall reflections (is this correct?)
- Edge diffraction at the compact range reflector
- Multiple reflections between the AUT and the compact range

The final result is formed as a complex far-field average of all 12 available patterns.

The measurements at UPM (spherical near-field facility) consisted of in total 18 full-sphere near-field acquisitions, which were aimed at estimate of influence and at reduction of the following uncertainties:

- Mechanical uncertainties of the setup
- Chamber reflections
- Mounting structure interference
- Receiver non-linearity
- Multiple reflections between the AUT and probe
- Amplitude and phase drift and noise

The final result is formed as a complex far-field average of ??? available patterns.

While data processing and forming the averaged patterns is completed, compilation of the uncertainty estimates is still on-going at the facilities. The last are necessary for the forming of the reference pattern by averaging the results from different facilities with weights inversely proportional to the estimated uncertainties.

Some results of investigation of the above uncertainties in the participating facilities are presented in a companion paper “Characterization of measurement systems through extensive measurement campaigns”.

6. Summary

The existence of an accurate reference pattern of a reference antenna allows benchmarking of the antenna test ranges and estimating their measurement uncertainties. Three possible approaches for definition of a highly accurate reference pattern were discussed. A dedicated measurement campaign carried out in 2007-2008 for definition of the highly accurate reference pattern of the VAST12 antenna was described. Conclusions from the first comparison campaign with the VAST12 carried out within the ACE network in 2004-2005 were taken into account and these were also presented and discussed. Some typical measurement errors and uncertainties are listed and briefly discussed.

7. REFERENCES

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